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HEWLETT-PACKARD V

Microwave Switch (A)

Engineers at Hewlett-Packard Associates have been involved for several years in the design and development of a high-speed, broadband microwave switch.

Previously available switching devices for use at microwave frequencies left much to be desired in terms of bandwidth and isolation.

Many problems arose in the development of a microwave switch with large bandwidth, low insertion loss, and high isolation. Among these were: 1) major electrical engineering innovations were required in developing the integrated circuitry of the switch, which is an order of magnitude improvement in the state-of-the-art over previously available equipment and, 2) the first switches used in the development phase of this program were made by a highly skilled technician A great many problems arose in transferring this design into the manufacturing phase.

Prepared at Stanford University during the 1966 National Science Foundation Summer Institute conducted by the Design Division of the Mechanical Engineering Department. The initial contact with Hewlett Packard Associates was made by Peter Z. Bulkeley. The case was prepared by Ward E. Bullock, State University of New York at Buffalo, James W. Hill, California State College at Long Beach, and George R. Powley, Virginia Polytechnic Institute, participants in the Summer Institute. Permission by Hewlett-Packard Associates to use this case for educational purposes is greatly appreciated.

Microwave Switch (A)

Bob Hall was thoroughly enjoying a long awaited vacation and yet he was bothered. Bob had a B. A. degree in physics and an M. S. degree in mathematics from Reed College and Stanford University respectively and had been working in industry for about five years. He was fascinated with his work involving microwave components; however, he was frustrated by his inability to come up with a solution to one problem that had been bugging him for a long time. Regardless of his efforts to the contrary Bob could not get the problem off his mind as vacation time drew rapidly to a close.

For the umpteenth time Bob turned the problem over in his mind. Available switching devices for use at microwave frequencies left much to be desired in terms of the frequency band over which they could be used effectively. Ideally speaking a switch should pass a signal with zero attenuation when in the ON state and conversely permit no signal to pass when in the OFF state. To the uninitiated this seems like a simple enough requirement to meet, and under d.c. or 60 cycle per second conditions it is. However, at microwave frequencies things are not always what they might seem. Consequently, a switch which might operate in an acceptable manner at 1000 mhz might not be at all satisfactory at 10,000 mhz.

Even at best, switches designed for microwave applications could not be expected to meet idealistic specifications. Figure 1 shows typical performance characteristics exhibited by switches available five years ago compared with the ideal. The limited bandwidth was a major deficiency and since the latest techniques using solid state devices were being utilized it was fairly obvious that a major breakthrough would be required to effect a solution. It was this major breakthrough for which Bob was seeking.

The bandwidth problems can be appreciated after considering the characteristics of the PIN diodes used in the manufacture of the switches. Figure 2 shows the equivalent circuit of the packaged unit. It should be noted that all circuit elements in the model are constant except R_i which varies with bias. At zero bias R_i will be around 10 K ohms and under reverse bias it will increase with magnitude of the bias to as much as 30 K ohms at about 20 volts. Over a wide range of frequencies the reactance of C_i will be considerably less than these values and the diode can be represented as shown in Figure 3. When forward bias is applied R_i becomes about one ohm and the equivalent circuit may be reduced to that shown in Figure 4.

If the diode described above is used as a series type switch it will have attenuation characteristics as shown in Figure 5. The peaks occur at the parallel resonant frequencies for the two respective biasing conditions and the dip in the reverse bias curve occurs at the frequency for which L_p and C_i are series resonant. As can be seen from Figure 5

the diode switch can never be considered completely OFF or completely ON, and its ability to attenuate varies considerably with frequency for both biasing conditions. Considering both ON and OFF capabilities the optimum range of operation (Bandwidth) lies between f_1 and f_2 on the frequency axis.

It should be noted that Figure 5 is drawn on the assumption that C_p and C_i are equal in magnitude when in reality they may be different. An inequality in C_p and C_i simply results in a shifting of the two curves laterally relative to each other since the parallel resonant condition when forward biased does not occur at the same frequency as the series resonant condition when reversed biased.

In a practical case diode switches built five years ago had a bandwidth of 2 ghz to 4 ghz as indicated in Figure 1. In many applications this was adequate. However, there was a growing demand for switches with much greater bandwidth and so far no one had been able to produce such a switch.

Bob had gone over all of this many times before without coming up with anything that looked hopeful. However, on this occasion something clicked in his mind. His thoughts ran something like this:

1. The bandwidth limits are directly related to the resonant conditions in the diode.

2. If resonance could be eliminated it might be possible to take an entirely different view to the problem and hopefully have attenuation characteristics like those in Figure 6.

3. The resonant conditions exist because of L_p, C_p, and C_i which are elements that are inherent to the diode chip and its package. If they could be eliminated, or a least drastically reduced, the solution to the problem might be within reach.

4. The only way to eliminate L_p and C_p would be to eliminate the package and you can't do that - or can you? Maybe it is possible to mount the chip in such a way as to make the package unnecessary.

Bob suddenly realized that he was on the edge of the breakthrough for which he had been searching. The idea of eliminating the package hence the capacitance and inductance associated therewith made him feel real good inside. To be sure there were many problems ahead, many of which he could not foresee. However, he was sure that he was on to something big and now it was time to really enjoy those last few days of vacation.

		Ideal	Practical (Packaged diode)
Insertion Loss (db) (Sw. ON)	$10 \text{ Log } \frac{P_{in}}{P_{out}}$	0	1
Isolation Loss (db) (Sw. OFF)	$10 \text{ Log } \frac{P_{in}}{P_{out}}$	Inf.	20
Bandwidth		Inf.	2 ghz - 4 ghz

Figure A-1

R_i - resistance of I layer
C_i - capacitance across I layer
L_p - package inductance
C_p - package capacitance
R_s - contact resistance

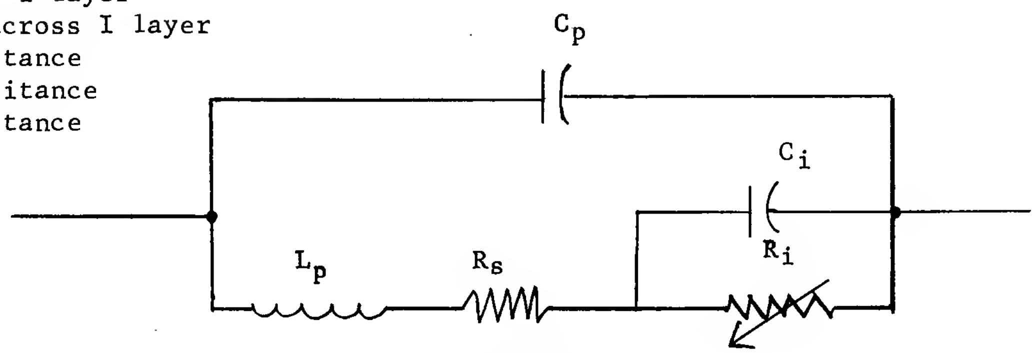


Figure A-2

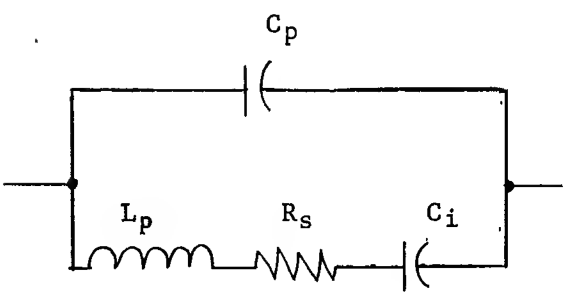


Figure A-3

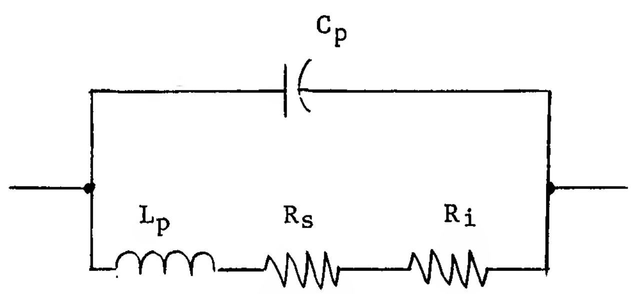


Figure A-4

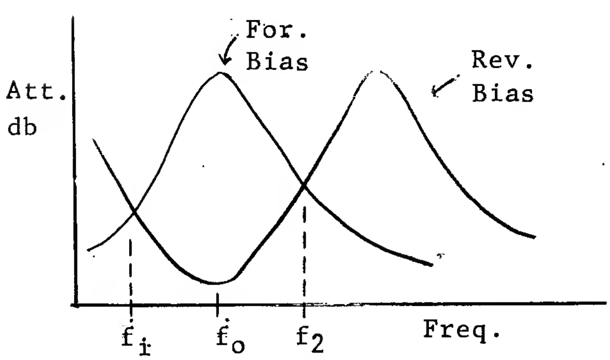


Figure A-5

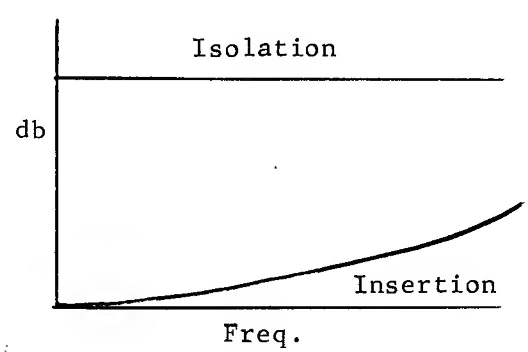


Figure A-6

Hewlett-Packard Associates Application Note No. 4

THE PIN DIODE

Basic Description

The PIN diode is better described as a variable resistor than as a conventional diode. Its normal use is at a sufficiently high frequency that it does not rectify the applied signal and does not generate harmonics. The resistance of the PIN diode is controlled by a dc or low frequency bias or modulating signal. The high-frequency signal which is being controlled sees a constant resistance independent of polarity although limited by reverse breakdown voltage.

This characteristic of the PIN diode depends upon the minority carrier lifetime being much longer than the period of the controlled signal.

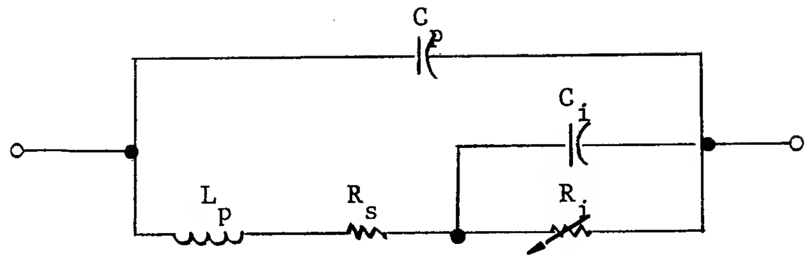
The dynamic resistance of the PIN diode can be larger than 10,000 ohms because of the existence of an exceptionally wide, high resistivity layer next to the junction. Because of this layer, the reverse breakdown voltage of the PIN diode can be very high (several hundred volts). Correspondingly, capacitance per unit of junction area will be very low, and yet conductivity during forward conduction can be high because the conductivity of this layer will be increased by the presence of stored charge (conductivity modulation).

These properties make PIN diodes useful as variable series or shunt resistive elements in microwave transmission lines. Maximum switching ratios can be achieved by operating PIN diodes in structures wherein they become series resonant at the microwave frequency for reverse bias and parallel resonant under forward bias, or vice versa.

In order to gain the maximum spread between the low and the high impedance condition for the PIN diode, it is required that the residual series resistance and junction capacitance be as low as possible.

A frequent conflict in the application of the PIN diode arises from the requirement that the minority carrier lifetime must be compromised between low rectification and harmonic generation on one hand, and reasonably fast switching speed on the other. It is generally possible to achieve speeds faster than 30 ns with low harmonic generation down to about 500 mhz.

Equivalent Circuit



L_p - package inductance ≈ 3 nh, depends upon mounting.

C_p - package capacitance ≈ 0.12 pf.

C_i - capacitance across I layer ≈ 0.07 pf.

R_s - contact resistance ≈ 1 ohm.

R_i - resistance of I layer (see text).

FIGURE 1 - Overall Equivalent Circuit

From the foregoing equivalent circuit, it can be seen that C_i remains essentially fixed and independent of bias condition, whether forward or reversed. This behavior is quite different from that of varactor diodes, for instance, where effective capacitance is very much bias dependent. The reason for this difference lies in the much higher resistivity of the PIN diode I layer so that the reactance of the capacitance of both the depleted and undepleted regions under reverse bias will be less than the resistances of these regions. Accordingly, the dissipative component (which is expressed here as resistance R_i) will vary with bias, but the capacitance C_i will not.

Under forward bias, the injection and subsequent storage of minority carriers acts to reduce the resistance of the I region in a uniform fashion.

The variation of R_i with bias can be described in the following terms:

At zero bias, the bulk resistance of the I region will be 7K to 10K ohms. This value comes from consideration of the junction area, I region width, and resistivity. Under reverse bias, a depletion region develops and the dissipative losses associated with this region will be less than that of the I region. Therefore, as reverse bias increases, the depletion layer widens, and the losses that are associated with this I layer capacitance will decrease, and so R_i

increases. At about 20 volts reverse bias, R_i will have risen to about three times its zero bias value.

Going toward forward bias, conductivity modulation will cause R_i to drop very rapidly with forward current. At high forward current this relationship will be:

$$R_i = \frac{K_g}{I^{0.87}}$$

where = I is forward bias current-ma
K_g varies from 20 to 50 ohms

At low forward bias, R_i will be approximately the parallel combination of this value and the zero bias value.

Applications

There are two general areas of application for the PIN diode; it may be used as a microwave switch to be operated by abrupt changes in bias or it may be used as a variable resistance microwave amplitude modulator. In either case, the impedance of the diode is controlled by external bias, and it approximates a linear passive impedance to the applied microwave signal.

The advantages of PIN diodes over ordinary diodes in switching applications are mainly, low capacitance, high breakdown voltage, low series resistance, and inability to follow instantaneous signal changes at microwave frequencies because minority carrier lifetime is much longer than the microwave signal period. Accordingly R_i does not change appreciably during a cycle of the applied RF signal and therefore the device behaves as a passive resistance. In switching applications this means that R_i will effectively remain at its biased value despite large excursions of applied signal, and consequently a PIN diode can handle almost twice as much signal voltage as a conventional diode with the same reverse breakdown voltage. Furthermore, the conventional diode requires a reverse bias equal to the peak signal voltage in order to maintain a low-conduction condition through a signal cycle, while a PIN diode does not require a reverse bias, although in some applications it might be desirable to use reverse bias in order to reduce leakage.

Basic Switch Applications of the PIN Diode

In switching applications there are two basic types of switches: broadband and resonant. These may each be further classified as series or shunt. As a matter of definition, a switch will be regarded

as "closed" when it permits most of the RF power from the generator to reach the load, and "open" when most of the RF power from the generator fails to reach the load, being either absorbed or reflected.

Broadband switches operate on the principle of changing resistance, and the inevitable parasitic reactances constitute their upper frequency limit of operation. Insertion losses and isolation properties are determined by the upper and lower limits of the resistance change.

HEWLETT-PACKARD V

Microwave Switch (B)

Bob Hall's comment about his "flash of genius" realization that the problem with microwave switches was not inherent in the diode chip but was due to the parasitic elements introduced by the diode package, was, "It freed the imagination. Then I could think in a free-wheeling way about all sorts of possibilities."

One of the possibilities he thought of was to bury the diode chip in a filter network. The network could then have two states or types of characteristics, one when the diode was reverse-biased and an entirely different characteristic when the diode was forward-biased. If the diode chip is connected between two capacitors as in Figure B-1, the network can be designed as a combination of a broadband filter and a shunt switch.

At microwave frequencies the connections between the diode and the two capacitors act as transmission lines having distributed inductance. Under reverse-bias or zero-bias conditions the diode acts as a capacitor in parallel with a very high resistance. Neglecting the high resistance, the network then has the equivalent circuit of Figure B-2, which can be designed as a broadband filter with a 50 ohm characteristic impedance.

When the diode in Figure B-1 is forward-biased its resistance drops to a very low value, typically less than 1 ohm. Under these conditions the diode capacitance can be neglected, and the equivalent network then becomes that of Figure B-3, where the low diode resistance effectively shunts the RF signal to ground. Under these conditions the network becomes a badly mis-matched load which reflects the RF back to the source; very little RF is able to pass through the network to the load.

At this point Bob Hall had the basic concept of a successful microwave switch, but several problems were still to be solved. Some of these were obvious, such as supplying DC bias to the diode without introducing undesired effects on the RF signal, but others were to confront him as "bugs" in the hardware.

The bias problem could be solved by using blocking capacitors to control the path of the DC bias current, and using an inductance with a by-pass capacitor to prevent the RF from flowing in the external bias circuit. The blocking capacitors and the by-pass capacitor would need to be large enough to have negligible reactance at microwave frequencies. An equivalent circuit using this approach is shown in Figure B-4, where

C_1, C_2, and C_3 are the blocking and by-pass capacitors and L_1 is the RF blocking inductance.

A prototype switch using this circuit showed many of the desired characteristics of a microwave switch, but failed to provide as much isolation as wanted in the "OFF" condition, i.e., it allowed too much RF to pass to the load. Bob Hall reasoned that the isolation could be increased by using two diodes in parallel to lower the resistance to ground when the diodes were forward biased. This follows from the definition of isolation (or insertion loss):

$$a = \text{isolation} = 10 \log_{10} \frac{P_1}{P_2} \quad \text{decibels}$$

where P_1 = power to the load without the switch,

and P_2 = power to the load with the switch OFF.

When expressions for P_1 and P_2 are substituted, this reduces to:

$$a = 20 \log_{10} \left(1 + \frac{Z_0}{2R}\right) \quad \text{decibels}$$

where Z_0 is the characteristic impedance of the switch,

and R is the RF shunt resistance path of the switch in the OFF condition.

Thinking along these lines, Bob Hall had another brainstorm. As he explained it, "If we're going to use two diodes, why not use one of them to separate the RF and DC bias circuits and eliminate the need for the blocking inductance?" The result gave the equivalent circuit of Figure B-5.

The prototype switch based on this equivalent circuit presented Bob Hall with the first real "bug". The measured isolation provided by the switch in the OFF condition and the calculated isolation did not agree by a significant amount. What caused the discrepancy? The first thought was that one of the diodes might be defective or that moisture or dirt was providing a path for leakage currents, thus providing coupling between input and output of the switch. These were quickly checked and eliminated as the cause of the trouble. Progress stopped while Bob Hall thought. Finally, it occurred to him that one type of coupling had not been considered. Perhaps there was coupling between the diodes due to the magnetic fields around them which was reducing the isolation in the switch.

A shield between the two diodes was added to the switch, and the isolation increased. Further experimentation proved that the shielding between diodes must be as complete as possible in order to achieve high isolation.

At about this time the second bug showed up in one of the switches. The switch failed to turn ON when the diodes were changed from forward-bias to reverse-bias.

This brings up the subject of the "lifetime" of a diode. The term "lifetime" refers to the time a minority carrier will survive in a semiconductor. An electron in a P-type semiconductor or a hole in an N-type semiconductor will combine with one of the many carriers of the opposite type which are present, and vanish. Minority carriers are emitted into the base layer of a junction diode when the diode is forward-biased; this stores a charge in the diode. When the bias is reversed, the diode itself cannot be driven into reverse-bias until this charge is exhausted. In general, two diodes will not have equal lifetimes.

If a single diode has been forward-biased, and a reverse-bias voltage is applied, a reverse current will flow through the diode and quickly remove the stored charge. But if two diodes are in series, this reverse current can flow only until the stored charge is removed from the diode with the shorter lifetime, and a part of the stored charge is left on the diode with the longer lifetime. This charge can only be removed by the much slower process of decay of the minority carriers unless there exists an alternate path through which the charge can flow.

It was found that the failure of the microwave switch to turn ON was due to a difference in the lifetimes of the diodes D_1 and D_2 in Figure B-5. If D_1 has a longer lifetime than D_2, the reverse-bias voltage will remove the charge from D_2 but leave some charge on D_1. The charge on D_1 maintains a short circuit in the switch and RF cannot pass to the load. However, if D_2 has the longer lifetime, the charge on D_1 will be exhausted first, and the charge on D_2 will be removed by the negative half cycle of the RF current flowing through the external biasing circuit.

At this point the microwave switch was a proven success, although still only in the prototype stage of development. The switches used in the development stage were hand made by a highly skilled technician. A great many problems could still be expected in transferring this design into the manufacturing phase.

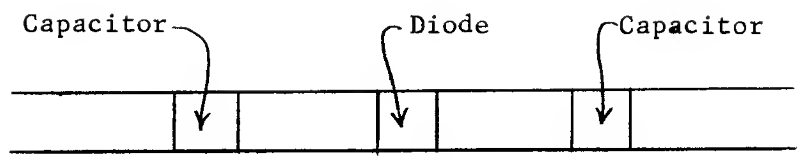


Figure B-1

Network Configuration

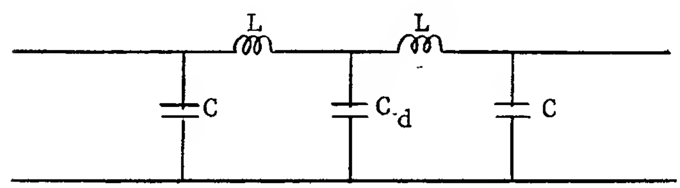


Figure B-2

Equivalent Circuit With Diode Reverse-Biased

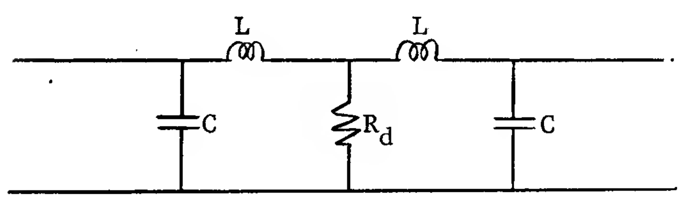


Figure B-3

Equivalent Circuit With Diode Forward-Biased

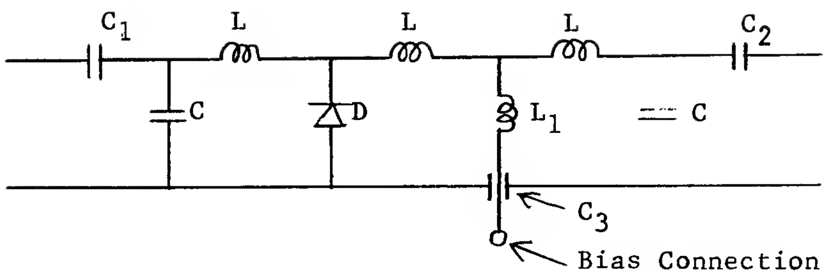


Figure B-4

Equivalent Circuit Showing Bias Connection

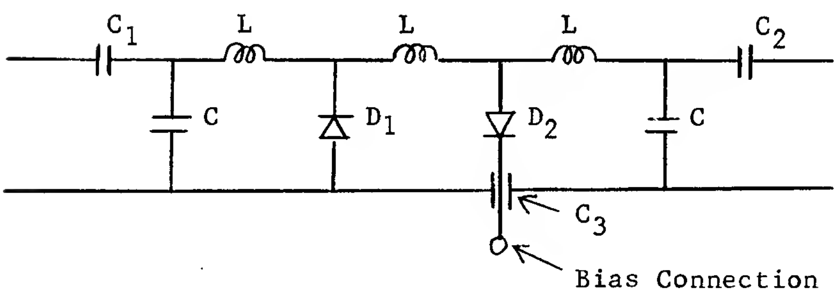


Figure B-5

Equivalent Circuit Using Two Diodes

HEWLETT-PACKARD V

Microwave Switch (C)

The transition of a product from the moment of its conception to its appearance on the market as a saleable item is generally not altogether smooth. The men at Hewlett-Packard Associates developed many a headache before the PIN Diode switch reached its marketable state and, of course, improvements are still being made.

To appreciate some of the production problems, perhaps it would be well to examine the various manufacturing steps required. Hewlett-Packard Associates, however, does not itself manufacture all parts of this switch. The housing and cover (Roger Nelson, who has responsibility for product development refers to the "house" rather than the housing) are supplied by vendors who seem to do a very satisfactory job. So far as has been learned the vendors have no insurmountable difficulties in spite of the fact that this is essentially a precision job and a number of the tolerances specified are very close. Exhibit C-1 indicates the locations of certain of these critical spots.

One might question some of the close tolerances; for instance, why the dimensions A $^{+.001}_{-.000}$ in the housing and the corresponding B $^{+.000}_{-.001}$ on the housing cover? Or why the polished surfaces on certain faces of these two mating parts? Roger Nelson said that the polished surfaces probably weren't really necessary but a good smooth surface certainly was required in order that the O-ring seal be properly effective. Bill Nelson felt that they had initially been unnecessarily fussy. However, the A $^{+.001}_{-.000}$ and B $^{+.000}_{-.001}$ really were essential in order to prevent excessive microwave leakage through the annular space between these mating parts. A still more accurate fit might be desirable from the standpoint of leakage but this would increase the cost and make assembly more difficult. The leakage loss sustained with the present fits is considered acceptable. The depth of the A diameter hole, its surface finish and the height of the corresponding housing cover tongue as well as the surface finish of its outer face are similarly specified to provide good metallic contact and minimize the microwave leakage. The designer-engineer must be careful not to specify unreasonably close tolerances but, on the other hand, some very precise dimensions may be required for the success of the product.

We shall not specifically mention other necessary operations on the housing and the housing cap even though many such are necessary; proper degreasing and painting, for instance. Such operations as these are mundane, to be sure, but very necessary for complete success of the product.

Although the manufacture of most of the individual components of this switch had its problems, these do not appear to have caused more than ordinary difficulties. However, at appropriate points, any particular difficulties and their remedies will be described. We proceed rather to the assembly of the device.

Exploded views will be used to provide an idea of the many small parts which must be assembled and their assembly sequence. In these views there is, in some instances, a faint resemblance to the actual part item. In one or two cases, also, the actual dimensions are supplied so that some idea of the relative sizes of these parts can be obtained. Refer to Exhibit C-2.

With the exception of parts numbered 1 through 5, all of these components are assembled into the housing with the assistance of a jig. The entire jig, with its assembled parts is then placed in a brazing furnace where the various preforms, in melting, produce the required bonding of the assembly. It may be of interest to note that the young woman who assembles these components handles the large ones with tweezers, very small ones, such as the 0.055 x 0.022 x 0.002 AuGe preforms, with an aspirator tube, and checks the centering of the bias pin by use of a 30 magnification microscope.

In describing some of the problems encountered, Bob Hall explained that selection of materials had been a problem because of the different rates of expansion encountered. Buckling of the ladder assembly, a key part of the switch had been encountered. Somewhat similarly, not all preforms could be made from the same materials since each successive pass through the brazing furnace would have to be at a lower temperature in order that the previous assemblies might not be destroyed. With this in mind, it is easy to realize that final assembly operations would have to take place at relatively low temperatures.

The ladder assembly, as indicated above, is a key portion of this microwave switch and its assembly is of extreme interest, essentially because of the very small components involved. Suppose we look at the parts of this small subassembly and then visualize the procedure of the assembler as she puts them together. Refer to Exhibit C-3. When assembled, by use of a special conducting epoxy the "ladder" appears as in Exhibit C-4 when viewed from G to F.

If one of these diodes were placed on this sheet of paper it would appear as "." or a little smaller. Try to imagine yourself handling such a minute item and bonding it securely to accurately located positions on the 0.001 thick gold ribbon! Admittedly, the job is simplified by the use of a special purpose assembly device adequately equipped with a ribbon feeder, micrometer adjusting screws, mechanized hold-down clamps, the entire sequence being observed under a microscope. Observing the operations through this microscope the illusion is that of dealing with rather large components. The assembly of the diodes to the gold ribbon is accomplished by thermal compression bonding, the parts being successively

pressed together and onto a backing plate which is maintained at about 300 degrees F. temperature.

The handling of the diodes is particularly interesting. Suppose we examine one of the diodes more closely. See Exhibit C-5. This diode actually consists of three parts, indicated as P. I. and N. Under the microscope the boundaries between the segments are quite visible but these boundaries must not be disturbed else the usefulness of the diode will be lost. Shall we pick up the diode with tweezers? Yes, of course, but we simply <u>touch</u> the corner of the diode with the tweezers (as at L), the diode adheres to the tweezers and can then be assembled to the ribbon. Can you see how this can be done, accurately and without delay?

There is another problem for the assembler to overcome. When selecting the diodes for specific positions on the ribbon the assembler must be sure to select the correct one for each position - for they are not the same. Since this difference cannot be determined visually but rather by previous test, she must select individual diodes from the proper supply source before bonding them into position. Then, when the ladder assembly is assembled into the housing these two different diodes must always occupy the same relative positions in the switch else the device will not operate. Note also that the two ends of the diode are not exactly the same. This slight difference also is a help to the operator during this assembly process.

The bias capacitor located under the bias pin caused some difficulties. These tiny plates, of a special ceramic material were initially sized by use of a sand-blasting technique. It developed, however, that the rough surfaces produced by this process created shorting difficulties. An ultra-sonic cutting technique presently is being successfully used - a definite improvement over the sand-blasting procedure.

The technique of assembling the ladder assembly to the housing is also intriguing. Again, this is largely due to the delicacy of the operation. The sketch, Exhibit C-6, indicates just where electrical connections must be made.

At surfaces A, B, C, and D there must exist a firm bond. At present the bonding agent is a DuPont Silver Conductive epoxy which is applied to the two mating surfaces with the assistance of the point of a common pin. The assembler mentioned that a pin was a very useful tool because an exceedingly small quantity of the epoxy should be used for proper results. This certainly has a logical sound when the areas of the surfaces involved are considered. It appears that even though the pin-point applicator is reasonably successful, it would be better if a still smaller quantity of epoxy could be delivered to the surfaces for, as one of the assemblers put it, "select the minimum amount of epoxy you need, then divide by 10 to get the proper amount."

When this assembly has been carefully positioned on the epoxy-treated surfaces in the housing, small quartz weights are placed in

strategic locations to insure that proper contact between the bonded surfaces is maintained while the assembly moves through the curing oven. Here the temperature is maintained at 500 degrees F. for one hour at the end of which time an excellent, durable bond has been established. Roger Nelson, however pointed out that this success had not been achieved except after many trials and failures. In the early days of production, poor bonding often resulted and this necessitated the scrapping of at least the ladder assembly and sometimes even the entire switch. In certain situations repairs were possible but this did not appear to be the rule.

In the area of the bias pin there seemed, initially, to be particular difficulty. Originally this pin was made of brass and the bias capacitor upon which the head of the pin rests was a barium strontium titanate wafer 0.020 inches thick. A solder was used at this connection and this solder would overflow and cause a short circuit. Furthermore, the capacitor itself, which was doughnut shaped, would crack due to temperature changes. In the process of evolution, however, the pin was changed to stainless steel and the capacitor greatly reduced in thickness and thus improved in strength. These changes, together with improved production techniques, have nearly done away with trouble.

As might be anticipated, too, there was considerable trouble with the vendors initially for they could not deliver components which were within specified tolerance limits. This is not an unusual situation, however, and the difficulties were gradually overcome so that at present they are largely non-existant.

Bob Hall said that although the epoxy-cementing technique is giving acceptable results they would very much like to substitute some type of welding process if someone could propose one which would be satisfactory. Also, they would be happier if a material having less variable properties than barium titanate could be substituted for the capacitors.

Now let us turn the spotlight on the housing cap. A few problems exist here even though this component does not contain any fragile parts. As its name seems to imply, the cap covers and protects the fragile housing components. In order to perform this function a very careful fit has been established. This has already been referred to in connection with problems involving microwave leakage. This accurate fit concerns not only the toleranced diameters shown here but also concerns the flat mating surfaces 3 and 4. When the housing cover is assembled to the housing the rubber O-ring bears on surface 2 and effectually inhibits the entrance of humid air which might cause a voltage breakdown of the diodes. It should be noted at this point that the metallic surfaces 1 and 2 do not come into contact with each other. Roger Nelson said that microwave leakage is still a problem even though it has been reduced to a tolerable level. Obviously, the complete elimination of leakage would be desirable but this, at least partially, involves the economics of manufacture and of course it is unlikely that 100% efficiency with respect to leakage could ever be achieved.

The tuning screws present no construction problem nor any assembly problem, as such, but the necessity for tapping holes to receive these screws does create a problem. In spite of the extreme care that is exercised in cleaning these threaded holes following tapping, it appears impossible to completely eliminate all the resulting metal dust. The metal dust may get into the switch and result in a short circuit. What cleaning methods have been used? Washing, pneumatic cleaning and even ultra-sonic procedures - but still some of the difficulty persists. Might there exist some other procedure, either to improve the tuning procedure without the use of screw threads or to give more thorough cleaning?

As a matter of information. the O-ring seal has not always been used. Originally a solder preform was tried but under application of heat the preform didn't flow with sufficient uniformity to prevent breaches. It would freeze out in different thicknesses and thus prevent a good fit. In addition, some of the solder would overflow and mar the external appearance of the switch.

Throughout the construction of components and during the assembly of the switch, moisture has been a problem. Undoubtedly it will remain a problem but the expanded use of dessicators in most of the assembly stages has pretty well overcome any difficulties.

From time to time throughout this presentation, difficulties of one nature or another have been described. How do these presently affect the production schedule? Jim Grace, supervisor of the production line, said that about 2 out of 20 assemblies require repair so far as the assembly of the ladder into the housing is concerned. He seemed to feel that this was quite good even though a 100% perfect performance is the goal. Facts on other specific phases of the production cycle were unavailable but it appears that overall switch production has reached a level that would seem to indicate excellent success in the manufacture of a high precision product.

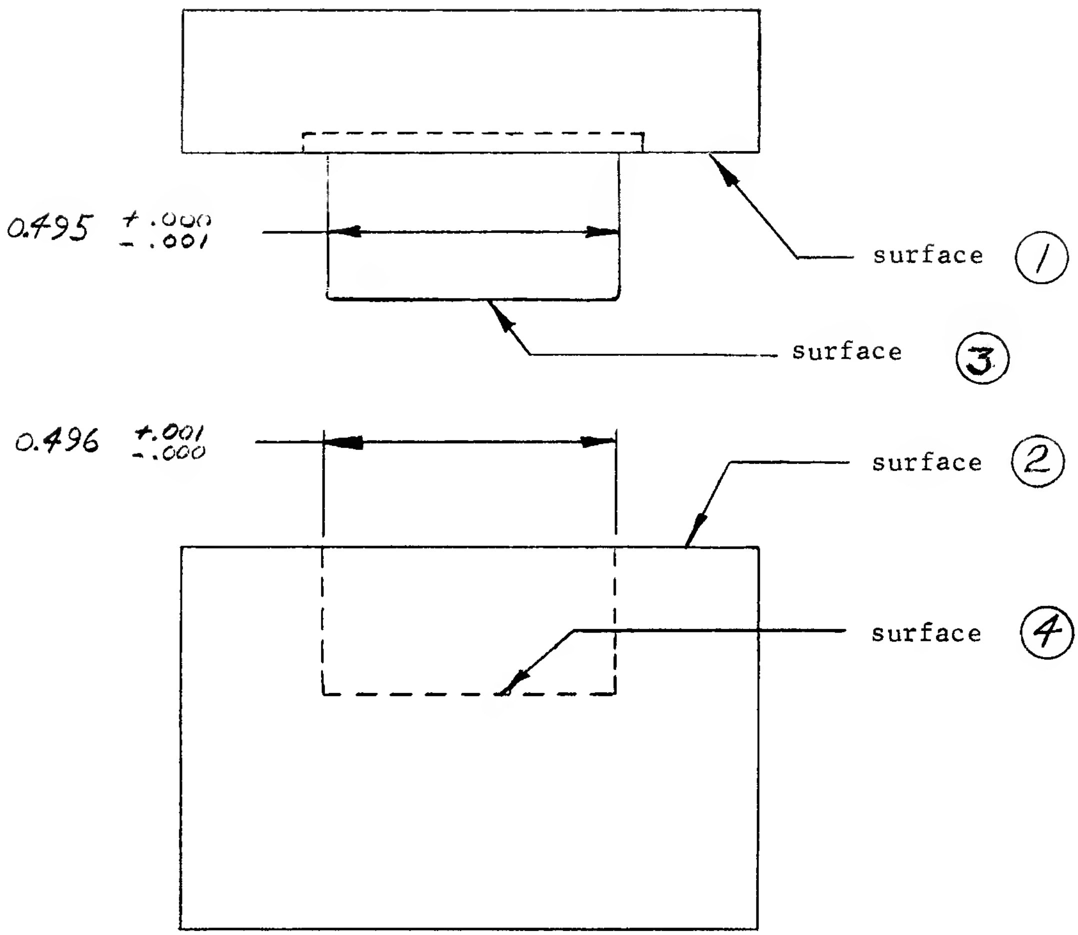

0.495 +.000 -.001
surface 1
surface 3
0.496 +.001 -.000
surface 2
surface 4

Exhibit C-1

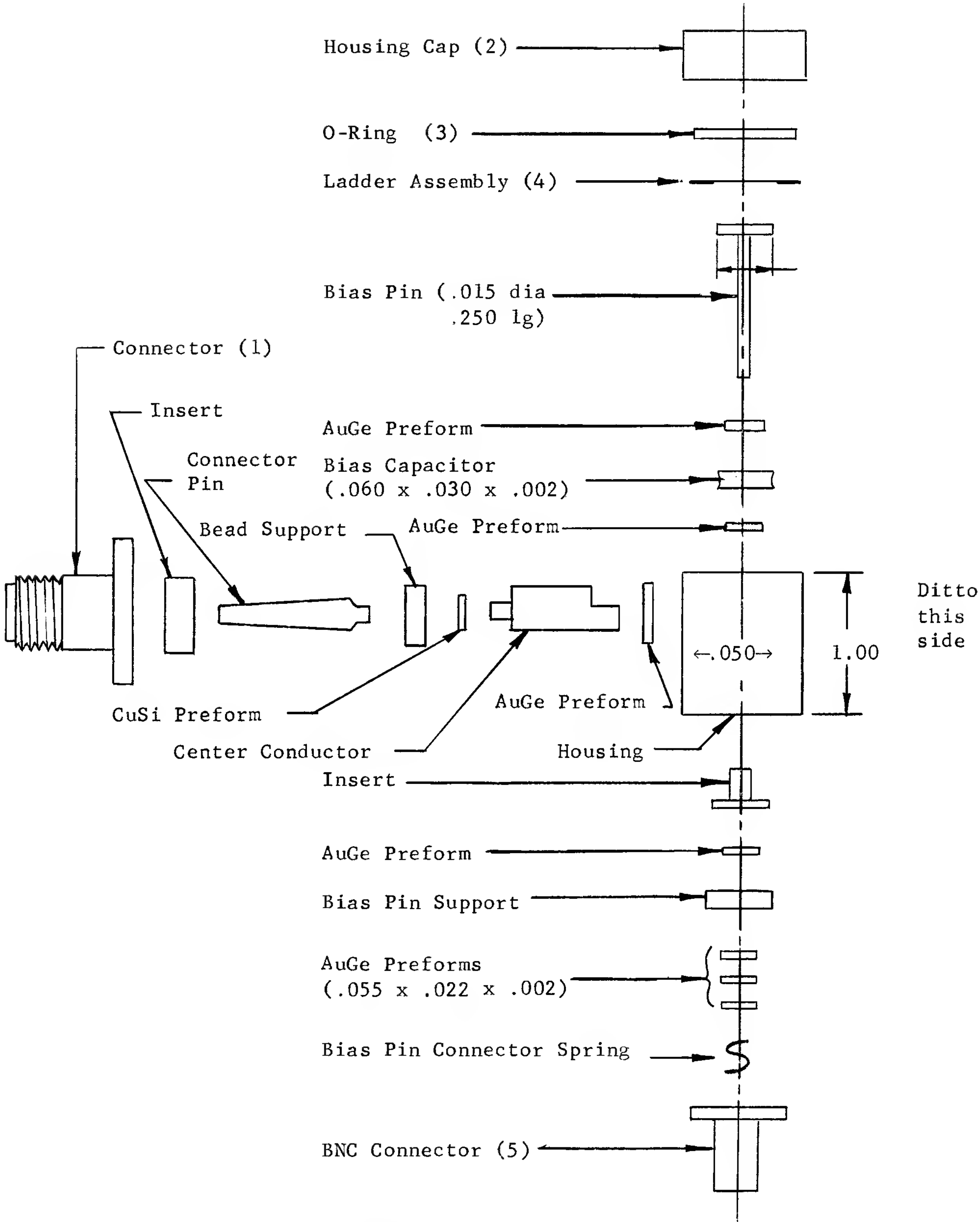

Housing Cap (2)
O-Ring (3)
Ladder Assembly (4)
Bias Pin (.015 dia
.250 lg)
Connector (1)
Insert
AuGe Preform
Connector
Pin
Bias Capacitor
(.060 x .030 x .002)
Bead Support
AuGe Preform
Ditto
this
side
.050
1.00
CuSi Preform
AuGe Preform
Center Conductor
Housing
Insert
AuGe Preform
Bias Pin Support
AuGe Preforms
(.055 x .022 x .002)
Bias Pin Connector Spring
BNC Connector (5)

Exhibit C-2

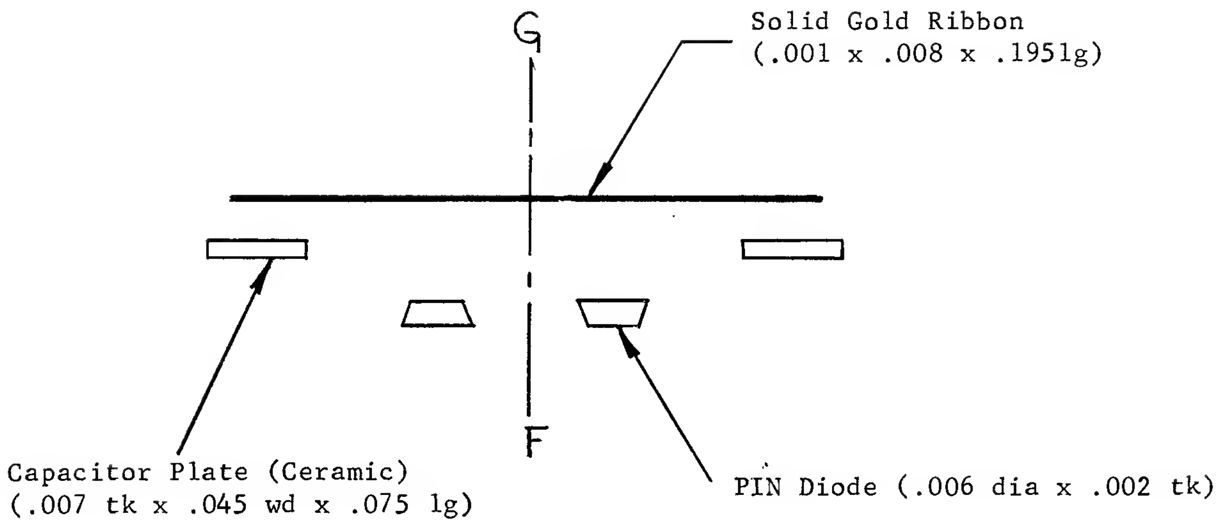


Exhibit C-3

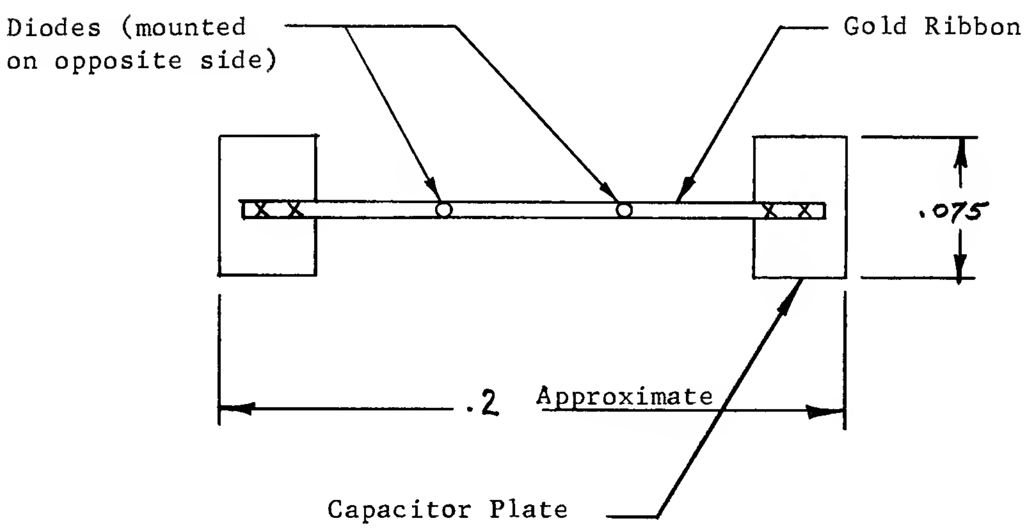


Exhibit C-4

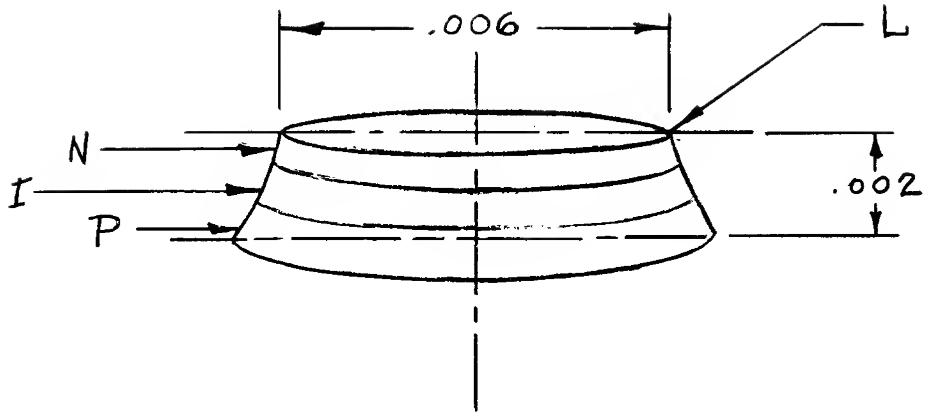


Exhibit C-5

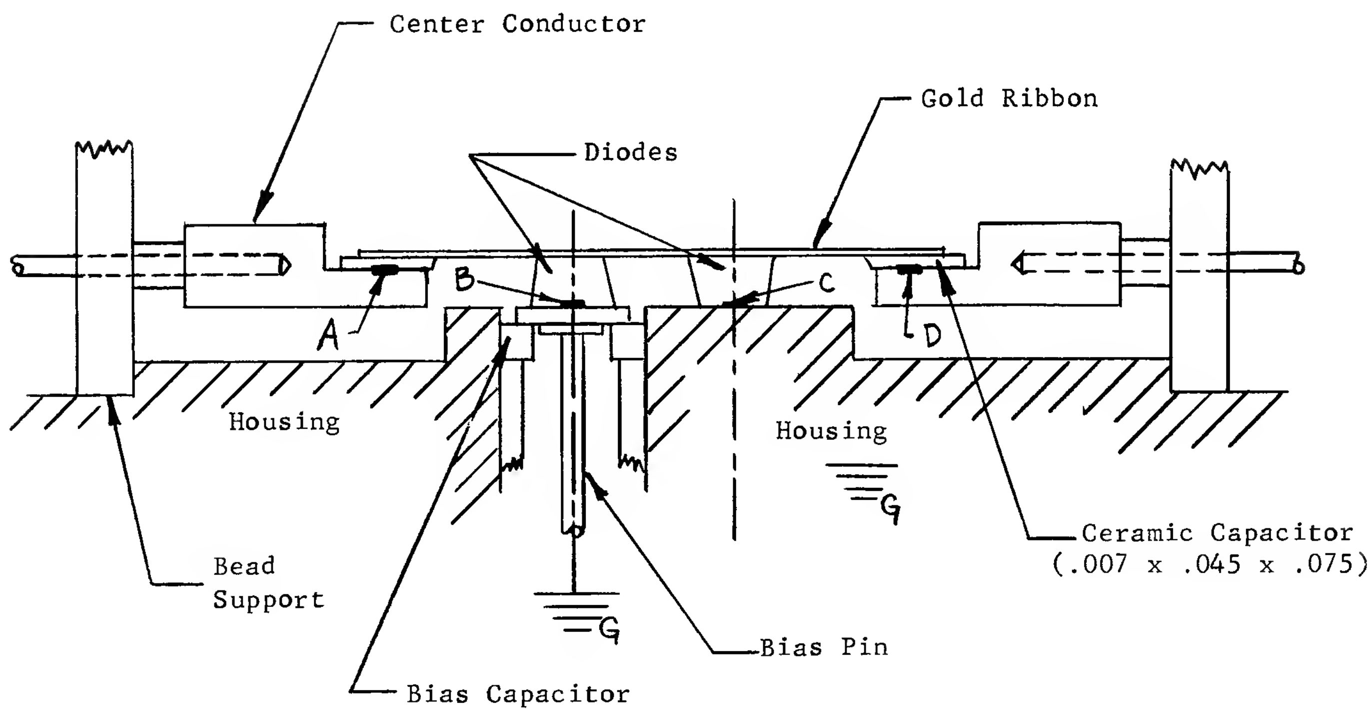


Exhibit C-6